IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

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To cite this article: J Vilches *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **503** 012069

IOP Conf. Series: Earth and Environmental Science **503** (2020) 012069 doi:10.1088/1755-1315/503/1/012069

Analysis of the Carbonation in Normal Concrete with the Addition of Tire Rubber Aggregate

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Abstract. Tires are an industrial waste that has become a worldwide environmental problem. To minimize this effect, tire waste is used in construction as a concrete aggregate. Additionally, carbon dioxide in the atmosphere affects the carbonation of concrete. This study analyzes the effect of carbonation in concrete with tire rubber aggregate as a 0%, 10%, 20%, 30%, 40%, 50% and 60% proportional replacement for the fine aggregate. The carbonation test was conducted for 2, 4, 6 and 24 hours. The compressive strength of the concrete decreased depending on the tire rubber content in the mixes, while the concretes with tire rubber percentages greater than 30% were affected by carbonation.

1. Introduction

The extraction of natural aggregates from riverbeds has caused enormous environmental problems. To counteract this problem, it is necessary to use alternative aggregates to manufacture concrete instead of conventional natural aggregates. In this vein, concrete has been produced with synthetic aggregates replacing natural aggregates [1]. Other studies have used industrial waste materials in the manufacture of concrete in order to minimize environmental effects [2], including rubber waste from tires. Several studies have analyzed the effects of these particles on the properties of concrete [3] [4] [5] [6]. An examination of these concretes revealed that the addition of tire rubber decreases the mix density and improves some of its properties, such as its: service life, fatigue strength, dynamic properties and ductility [7]. However, the incorporation of these particles negatively affects strength [8]. Furthermore, the addition of tire rubber particles improves thermal conductivity when the amount of rubber in the concrete increases [9].

The high alkalinity of concrete is chiefly due to the portlandite formed during the hydration of the cement's anhydrous compounds and the sodium, potassium and calcium hydroxides present in the mix. Alkalinity decreases when the basic compounds in the concrete's aqueous phase react with acidic components in the atmosphere, carbon dioxide and sulfur, to form carbonates, sulphates and water. Since carbon dioxide is found in greater proportion than sulfur in the air, this alkalinity reduction process is called "carbonation" [10].

Concrete porosity is fundamental in carbonation because the pores form the path for CO_2 to advance from the outside. In turn, porosity is affected by the: type and amount of cement, degree of compaction, curing time and method, and water-cement ratio. In general, a low water-cement ratio produces less permeable concrete, within acceptable hydration limits [11]. Another important factor is the concentration of CO_2 in the environment.

In this study, the standard UNE-EN-13295:2005 was used, which stipulates that to test carbonation, work must be carried out at a CO_2 concentration of 1% for 56 days at a controlled atmospheric pressure of 60% and 23°C.

Some studies have determined that carbonation depth is directly proportional to the increase in the percentage of tire rubber, thus deducing that the lack of adhesion between the cement paste and the tire rubber aggregate produces access routes into the internal part of the sample, which facilitates CO_2 penetration [12]. However, other studies have shown a significant decrease in carbonation depth in concretes that contain a 20% addition of tire rubber [13].

The objective of this research is to analyze the effect of carbonation in concrete with tire rubber aggregate as a 0%, 10%, 20%, 30%, 40%, 50% and 60% proportional replacement for the fine aggregate. The carbonation test was carried out for 2, 4, 6 and 24 hours in an accelerated carbonation chamber.

2. Materials and Methods

2.1. Tire rubber particles

Rubber particles were obtained by shredding tire waste. Then they were sifted through a No. 4 sieve and washed to remove dust and residue from shredding. Subsequently, the tire rubber particles were dried in an oven for 24 hours at 60°C. These particles were used to replace 10%, 20%, 30%, 40%, 50% and 60% of the fine aggregate. Figure 1 shows the tire rubber particles used in the mixtures.

Figure 1. Tire rubber aggregate

2.2. Concrete mix dosage

A total of 49 concrete specimens were prepared: 3, 15cm cubic specimens; and 4, 10cm diameter cylindrical specimens for each concentration of tire rubber addition replacing the fine aggregate (0%, 10%, 20%, 30%, 40%, 50% and 60 %). A concrete with a compressive strength of 35MPa designed with the Faury-Joisel method was used. This method consists in using an ideal curve, where aggregate proportions are determined based on their granulometry. As per standard NCh 148 Of. 68, high-strength cement was used. The physical properties of the aggregates, such as density, granulometry and absorption, were determined by means of standard NCh 163/2013.

2.3. Determination of workability

To evaluate the effects of the tire rubber aggregate on the workability of the concrete, slump was measured according to the procedure in standard NCh 1019/2009. An Abrams cone was placed on a metal base. Then it was filled with concrete in three layers, after each of which it was tamped 25 times. The last layer was evened off and the metal cone was lifted and placed upside down next to the concrete.

Lastly, the slump of the concrete was measured with respect to the height of the Abrams cone, as shown in Figure 2.

Figure 2. Slump of the concrete

2.4. Compression test of the cubic specimens

The concrete was poured into 15 cm metal cube molds. After 20 hours, the specimens were demolded and left to cure under water for 28 days. Subsequently, a compression test was conducted on the specimens. A test press, graduated ruler (caliper) and scale were used, as specified by standard NCh1037/2009. The specimens were placed in the test press and the load was applied until the failure load was reached. A Pinzuar model PC-42 test press was used with a range of measurement of up to 2000kN, as shown in Figure 3.

Figure 3. Compressive strength test

2.5. Carbonation test according to standard UNE 112-011-94

This test consisted in placing the concrete specimens inside the carbonation chamber with a space between them so that the CO_2 penetrated evenly. The carbonation chamber was airtight, so the CO_2 inside acted at a constant pressure of less than 20 mbar. This pressure was checked for 15 minutes until it stabilized. The specimens were subjected to pressure for 2, 4, 6 and 24 hours respectively. The specimens were removed from the carbonation chamber and then cut with a diamond blade. Subsequently, a solution of phenolphthalein with 70° alcohol was sprayed on the specimens. This procedure must be completed within 15 minutes of specimen extraction. Finally, carbonation was measured according to standard UNE 112-011-94. Table 1 shows the pH ranges and degree of carbonation for different specimen colors. The carbonation chamber and specimens inside can be seen in Figure 4.

Table 1. Degree of carbonation according to color

Color	pH Range	Carbonation
Purplish red	9.5 < pH	Not carbonated
Light pink	8.5 < pH < 9.5	Partially carbonated
Normal color	pH < 8	Completely carbonated

Figure 4. Carbonation chamber

3. Results

3.1. Dosage summary

Table 2 shows the dosage results obtained by the Faury and Joisel method, modified by the Chilean Ministry of Public Works' Highway Laboratory. For the different mixes, a water/cement ratio of 0.52 was used. The fine aggregate was replaced with tire rubber aggregate in different percentages by volume.

Table 2. Dosage for 1m^3 of concrete with a compressive strength of 35 MPa

Material	**Unit**	**Percentage of tire rubber addition**						
		0%	**10%**	**20%**	**30%**	**40%**	**50%**	**60%**
Cement	kg/m^3	411.64	411.64	411.64	411.64	411.64	411.64	411.64
Gravel	kg/m^3	1081.17	1081.17	1081.17	1081.17	1081.17	1081.17	1081.17
Sand	kg/m^3	661.17	595.05	528.94	462.82	396.70	330.59	264.47
Water	L/m^3	215.00	215.00	215.00	215.00	215.00	215.00	215.00
Tire rubber	L/m^3	0.00	42.66	85.31	127.97	170.62	213.28	255.94

3.2. Determination of concrete workability – Abrams cone method

Figure 5 shows the slumps obtained in concrete with a compressive strength of 35 MPa with added tire rubber.

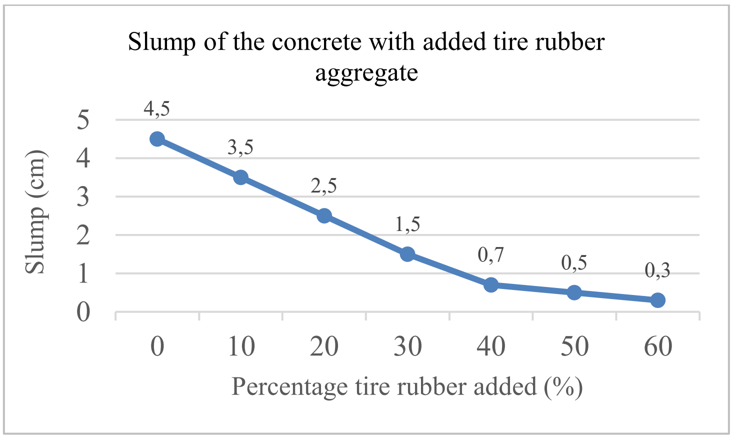

Figure 5. Slump of concrete with tire rubber addition.

In accordance with the data obtained, it can be observed that the concrete with 0%, 10% and 20% added tire rubber had a low degree of workability [14]. The concrete with 30%, 40%, 50% and 60% added tire rubber had a very low degree of workability [14].

The seven tests show varying decreasing slumps with respect to the control sample corresponding to 0% addition of tire rubber.

3.3. Apparent density of the concrete

According to the data obtained, density decreases as the addition of tire rubber increases, as shown in Figure 6.

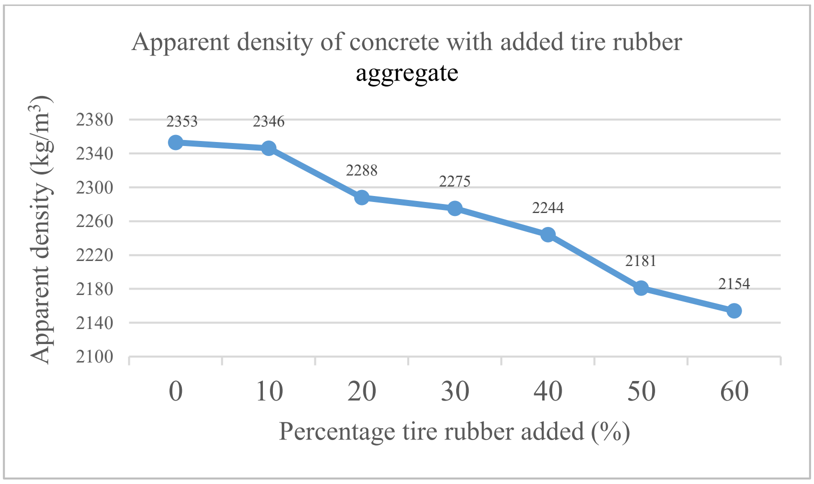

Figure 6. Apparent density of the concrete

Concrete with a 0%, 10%, 20%, 30%, 40%, 50% and 60% tire rubber addition, showed a decrease in density of from 0.3% to 8.46% in comparison with the control sample. This is primarily due to the characteristics of tire rubber aggregate, which is lower in density than the fine aggregate.

3.4. Compressive strength

Figure 7 presents the compressive strength results for the concrete evaluated with 15 cm cubic specimens at 28 days. The data collected shows that the higher the percentage of tire rubber aggregate, the lower its strength. The compressive strength of the specimens varied from -10.0% to -51.53% with respect to that of the control specimen. This is because the tire rubber particles added to the mixture have lower mechanical strength. The literature shows that there is a direct relationship between the mechanical strength of the concrete and its density, as shown in Figure 7.

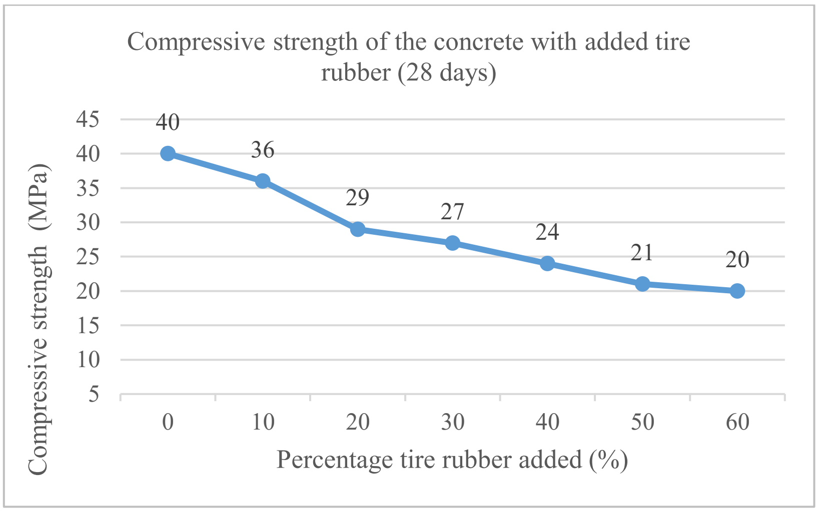

Figure 7. Compressive strength at 28 days

3.5. Carbonation

Carbonation was carried out in an acceleration chamber with cylindrical specimens, 10 cm in diameter and 20 cm in height, which were exposed for 2, 4, 6, and 24 hours.

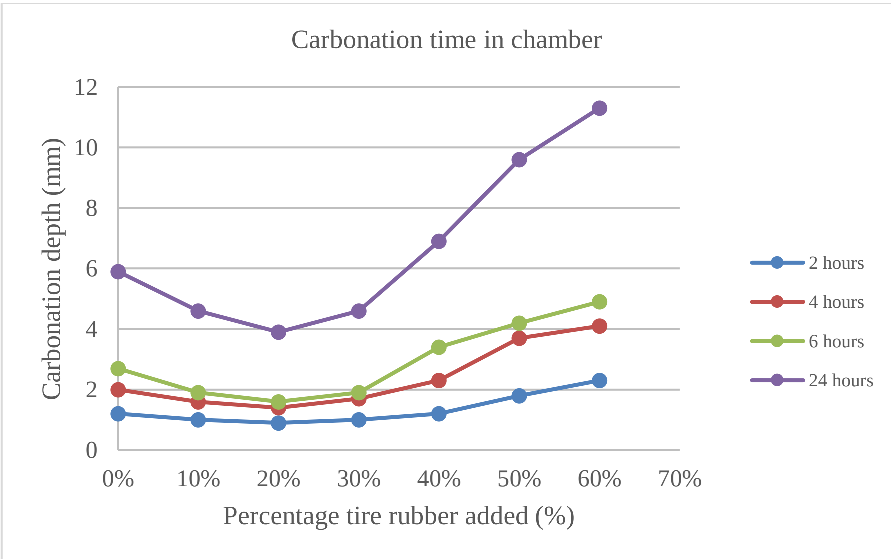

Figure 8. Carbonation depth after 24 hours in the chamber

It can be seen in Figure 8 that in the concrete with a 0 to 30% tire rubber addition, the carbonation depth decreased with respect to the control sample. Nevertheless, in concrete with 40% to 60% added tire rubber the carbonation depth was equivalent to or greater than that of the control sample. Both situations occurred in all tests regardless of the time inside the chamber.

3.6. Correlation between carbonation depth and compressive strength

Figure 9 shows the correlation between the results of CO^2 penetration from the carbonation process and the compressive strength of the normal concrete with tire rubber aggregate specimens, and the normal concrete specimens.

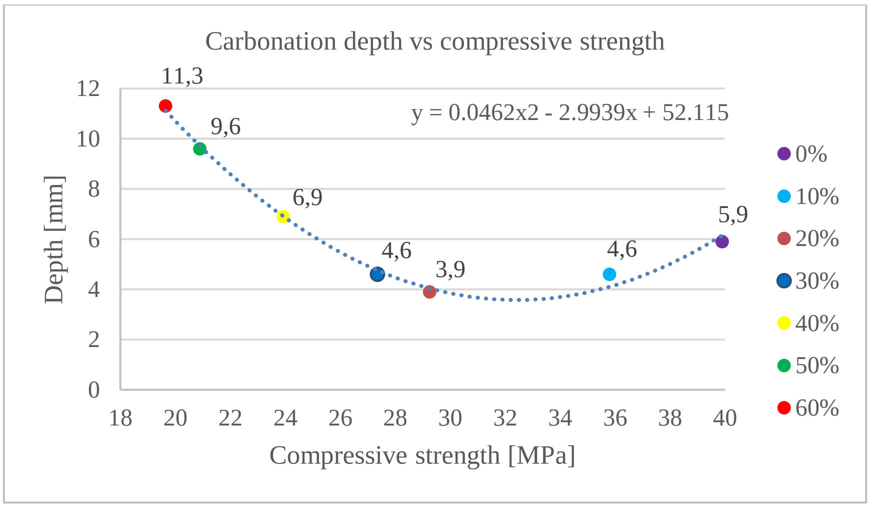

Figure 9. Carbonation depth vs compressive strength according to percentage tire rubber added.

According to Figure 9, it can be observed that there was a decreasing trend in compressive strength with respect to an increase in carbonation depth. In similar studies, concrete porosity decreases by adding up to 20% tire rubber aggregate. However, as the percentages of tire rubber added increase, the porosity behaves inversely, increasing the number of pores, which negatively affects the depth of carbonation.

3.7. Compressive strength in carbonated and non-carbonated samples

Figure 10 shows the variation in strength that was produced due to the effect of carbonation after 24 hours in the chamber.

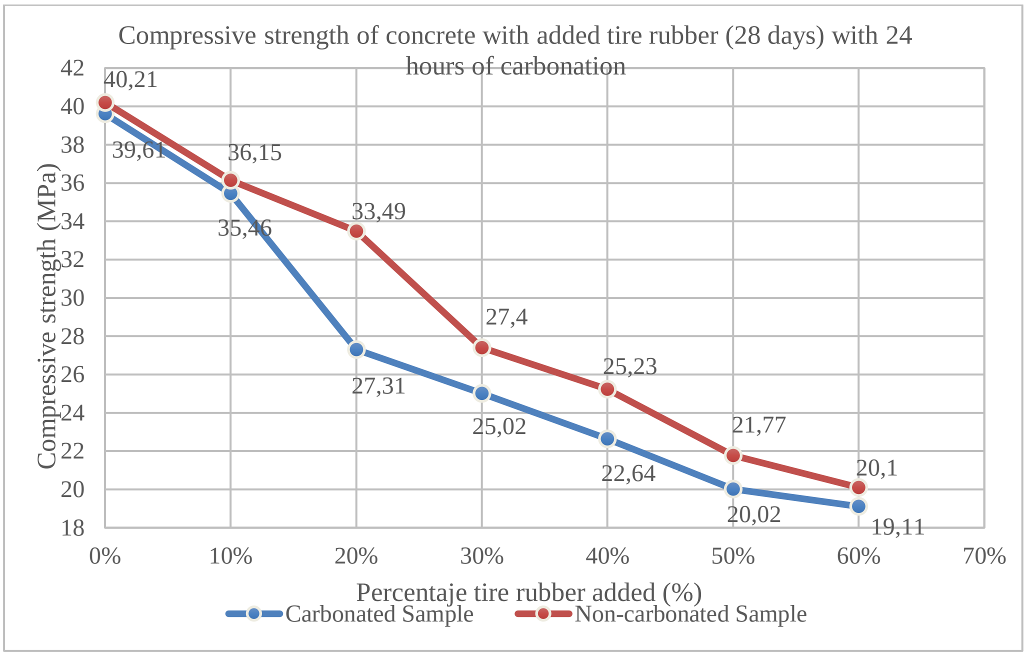

Figure 10. Correlation between carbonation depth and compressive strength

As the percentage of tire rubber in the mix increased, the compressive strength of the concrete decreased. In addition, the effect of carbonation on compressive strength can be observed.

4. Conclusions

The friction produced between the tire rubber particles and the stone aggregates could make it difficult for the particles to move in the mix, thereby causing a decrease in the concrete slump.

Tire rubber additions of between 10% and 30% decreased the penetration depth of CO_2 due to the effect of carbonation. However, percentages greater than 40% significantly increased carbonation depth compared to the 0% control sample.

As the addition of tire rubber increased, the compressive strength decreased considerably. This is mainly due to the lower stiffness of the rubber particles compared to the stone aggregates.

The results obtained show a descending line between the addition of tire rubber and compressive strength, given that upon carbonation concrete loses the mechanical properties of compressive strength. In relation to carbonation depth and compressive strength, at lower strengths the penetration of CO_2 tends to be greater because of the effect of carbonation. It can be concluded, as in similar investigations, that with tire rubber addition percentages of up to 20%, the porosity of the concrete decreases. However, by increasing the rubber addition percentages, the porosity behaves inversely, increasing the number of pores and thus enabling greater carbonation depth.

Tires are a waste material that has negative effects on the environment. However, they can be used successfully as an aggregate in low-strength concrete with a lower density than normal concrete, as shown in this study.

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